Study of the Moho Depth and Crustal V_p/V_s Variation in Southern California from Teleseismic Waveforms, 2000 Annual Project Summary

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1 Investigation undertaken

In the year 2000, we retrieved all available broadband three-component P waveforms of teleseismic earthquakes between January 1993 and December 1999 from the data center of the TERRAscope/TriNet network. Each seismogram was visually examined and low signal/noise ratio traces were discarded. In total, we have obtained 14,817 three-component records at 117 broadband stations from 500 teleseismic earthquakes. This includes 22 new TriNet stations (see Fig. 1) added to the previous 71 stations that we used to determine the Moho depths and crustal V_p/V_s ratios with our receiver function technique in 1998 [*Zhu and Kanamori*(2000),].

The data were processed according to the proposed research plan. We first picked the first arrival times from these records using a multi-channel cross-correlation technique. 14,418 high quality P picks were obtained. The effective source time function of each earthquake was estimated by stacking all vertical components of waveforms from the event, aligned on the first arrival. We then computed receiver function for each station by removing the source time function from the P waveforms. This was done using a frequency-domain deconvolution algorithm [*Zhu and Kanamori*(2000),]. The deconvolution results were visually checked and bad traces were discarded. From the 14,817 P waveforms, we obtained 9,320 receiver functions. They will be used to estimate the Moho depth and crustal V_p/V_s ratios in the next steps of data analysis.

In addition to collecting data from the permanent broadband stations, we also collected P waveform data recorded during several temporary seismic recording experiments in southern California. During the 1993 LARSE passive recording experiment, a 180 km–long profile, starting from the Los Angeles Basins through the San Gabriel Mountains (SGM), the San Andreas Fault (SAF), and into the Mojave Desert, was occupied by 89 short-period instruments, including 60 three-component instruments (Fig. 1). From this experiment, we obtained and processed 1,500 three-component short-period records from 30 teleseismic events. A similar experiment (LARSE-II) was conducted in 1998 and 1999 and 83 three-component broadband and short-period instruments were deployed along a second profile from the coast of Malibu through the San Fernando Valleys to the Mojave Desert (see Fig. 1). The experiment lasted 6 months and recorded numerous regional and teleseismic events. Correspondingly, we obtained 4,527 three-component P waveforms from 87 teleseismic events. All the waveform data from these experiments were processed in the same way as to the permanent station data described above. These two experiments provided in total 3,300 receiver functions.

To fully utilize the dense station distribution (1 to 2 km of station spacing) in the temporary experiments, we developed the Common Conversion Point (CCP) stacking technique to image the crustal structure along the profiles. We first calculate the ray-paths of the receiver functions using a background velocity model (a modified standard southern California velocity model). The amplitude at each point on the receiver function, after corrected for the incidence angle effect, is assigned to the corresponding location on the ray-path where the P-to-S conversion occurred, using its time delay with respect to the direct P. This amplitude represents the velocity change, or more precisely the

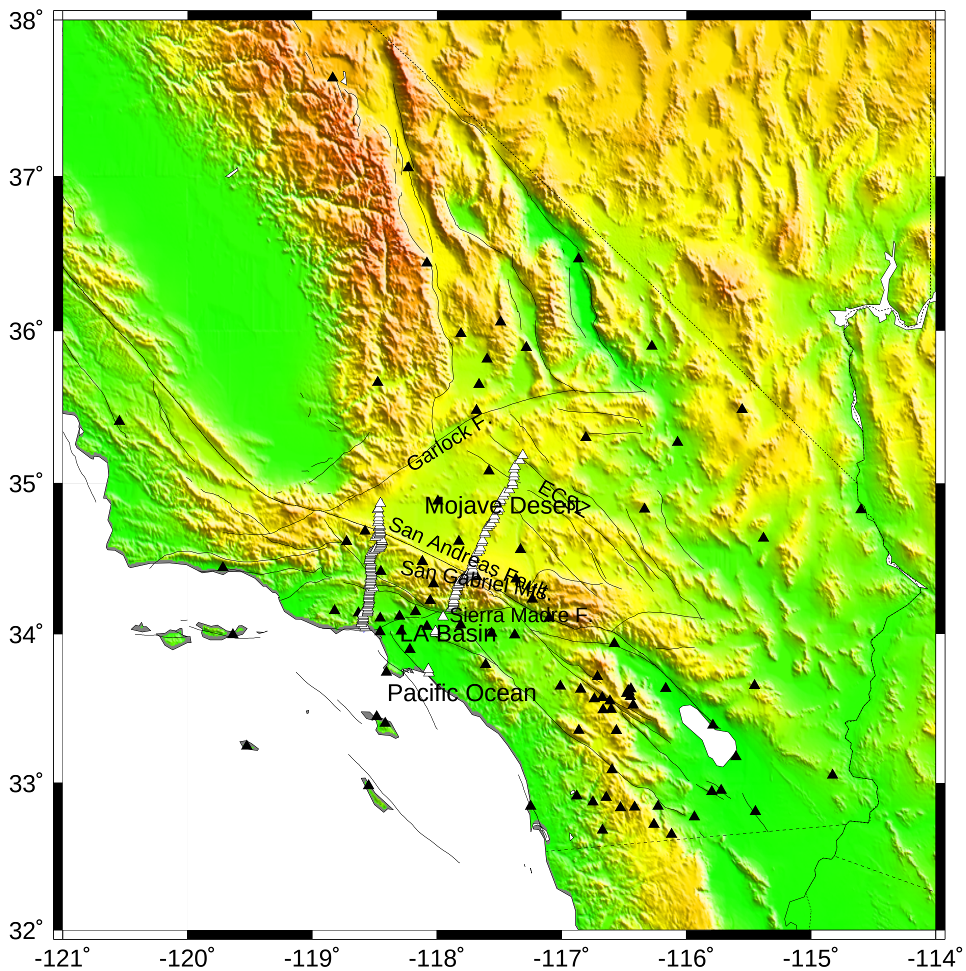

Figure 1: Locations of permanent TriNet stations (solid triangles) and temporary stations along two LARSE profiles (open triangles).

impedance change, of the medium at the conversion point. We then divide the volume along the profile into certain size bins and sum all amplitudes in each bin to obtain the average amplitude and variance. This technique is similar to the one used by Kosarev et al. [*Kosarev et al.*(1999)*Kosarev, Kind, Sobolev, Yuan, Hanka, and Oreshin*,], but different from the stacking technique by Dueker and Sheehan who bin ray-paths geographically according to their piercing points at certain depth and make the distance moveout correction before stacking [*Dueker and Sheehan*(1997),]. The horizontal dimensions of the bin size depend on the wavelength of signals and the vertical dimension is determined by the sampling rate of the receiver function. For this study, we used a bin size of 30 km wide, 7 to 9 km long, and 0.5 km high. Neighboring bins overlap by 6 to 8 km along the profile so that a smooth 2-D image of 1 km horizontal grid spacing is produced. This CCP stacking technique was applied successfully to the LARSE data.

2 Results

Figure 2 shows the CCP stacking amplitude along the LARSE-93 profile with the variances that are used to evaluate the stacking quality. The most prominent feature in the figure is the P-to-S conversions centered at a depth of 30 km, which we interpreted as the Moho discontinuity. It is flat beneath most of the Mojave Desert and deepens gradually to a depth of 35 km beneath the SAF. This continuous feature is apparently truncated by the downward extension of the fault. At the southern end of the profile the Moho shows up strongly at a depth of 30 km beneath the northern margin of the Los Angeles basin. Identifying the Moho between the basin and the SAF is hampered by the decreasing stacking quality under the SGM as indicated by the relatively large variances. This is probably caused by high noise level for this portion of the profile or it might reflect complicated structures under the mountain range. Nevertheless, the large Moho P-to-S conversion under the basin can be traced continuously northward to a shallower depth of 25 km under the SGM. We interpreted it as the Moho discontinuity simply because it is a continuous feature with large amplitude. Given the amplitude uncertainty and scattered conversion energy from the below, it might represent a lower-crustal discontinuity above a disrupted or diminished Moho in this part of the profile. However, our gravity modeling seems to support the shallow Moho interpretation. In any case, the SAF marks an abrupt change of the lower crustal structure as indicated by the truncations of the P-to-S conversions from the both sides. The result suggests that there is a Moho upwarp under the SGM and a vertical separation of the Moho by 6 to 8 km directly beneath the SAF. Under the Eastern California Shear Zone (ECSZ), the Moho is also offset, but to a lesser extent. In the uppermost mantle, P-to-S conversions are observed in isolated regions and mostly south of the SAF under the SGM. Within the crust, the largest amplitude conversions are in the top 5 km. The bottom of this zone varies laterally and can be correlated with surface geological features such as sedimentary basins and mountains. Therefore, they are most likely to be produced by the large velocity contrast between sedimentary material and basement rocks. In the mid-crust between depths of 15 and 20 km, there are several horizontally lying and discontinuous conversions that probably represent the interface between the upper and lower crust.

We also generated a 2-D crustal structure image along the LARSE-II profile using the same stacking technique (Fig. 3). The San Fernando Basin and the Santa Clarita Basin are well imaged with the basin bottoming at 6 to 8 km depth. In addition, a low-velocity patch exists near the surface under the Antelope Valley in Mojave Desert which might be an old sedimentary basin or low-velocity rocks. The Moho is seen clearly as a continuous flat feature at a depth of 34 km under the Mojave Desert. It is terminated near the downward extension of the SAF. The deep structure under the San Fernando and the Santa Clarita Basins is unclear. There is no detectable P-to-S conversions at a depth range of 20 to 40 km between the Santa Monica Mts. and the Western San Gabriel Mts. Instead, several offset conversion bands can be seen between depths range of 40 to 50 km, suggesting thickened crust. We also compared the teleseismic arrival time delays along the profile with the predictions from the inferred crustal model. The preliminary modeling shows that most of the anomalies can be explained by the shallow sedimentary basins.

3 Non-technical summary

Teleseismic earthquake waveform data recorded by the permanent TriNet stations between 1993 and 1999 and two temporary seismic experiments in southern California have been collected and processed. We also developed a new technique to image crustal structure and applied it to the data successfully. High-resolution crustal structures along two profiles in southern California were produced. The results show very rapid change of deep structure across the San Andreas fault and suggest that the fault penetrates the entire crust. Several sedimentary basins in the region are also revealed in great detail by our data.

4 Reports published

1. Zhu, L., 2000, Preliminary Results of Crustal Structure from the LARSE-II Passive Recording Experiment Using Teleseismic P-to-S Converted Waves (abstract), SCEC Annual Meeting, August 2000, Oxnard, CA.

2. Zhu, L. and M. D. Kohler, 2000, Preliminary Results of Crustal Structure from the LARSE-II Passive Recording Experiment Using Teleseismic P-to-S Converted Waves (abstract), AGU 2000 Fall meeting, San Francisco, CA.

5 Data availability

The estimated crustal thicknesses and V_p/V_s ratios of 71 broadband stations in southern California are available via anonymous ftp to earth.gps.caltech.edu. The results are in plain text format named as /pub/lupei/jgr2000.tbl. The Moho depth on a uniform grid of 0.1 degree spacing is also available in the GMT 2D grid format at the same location

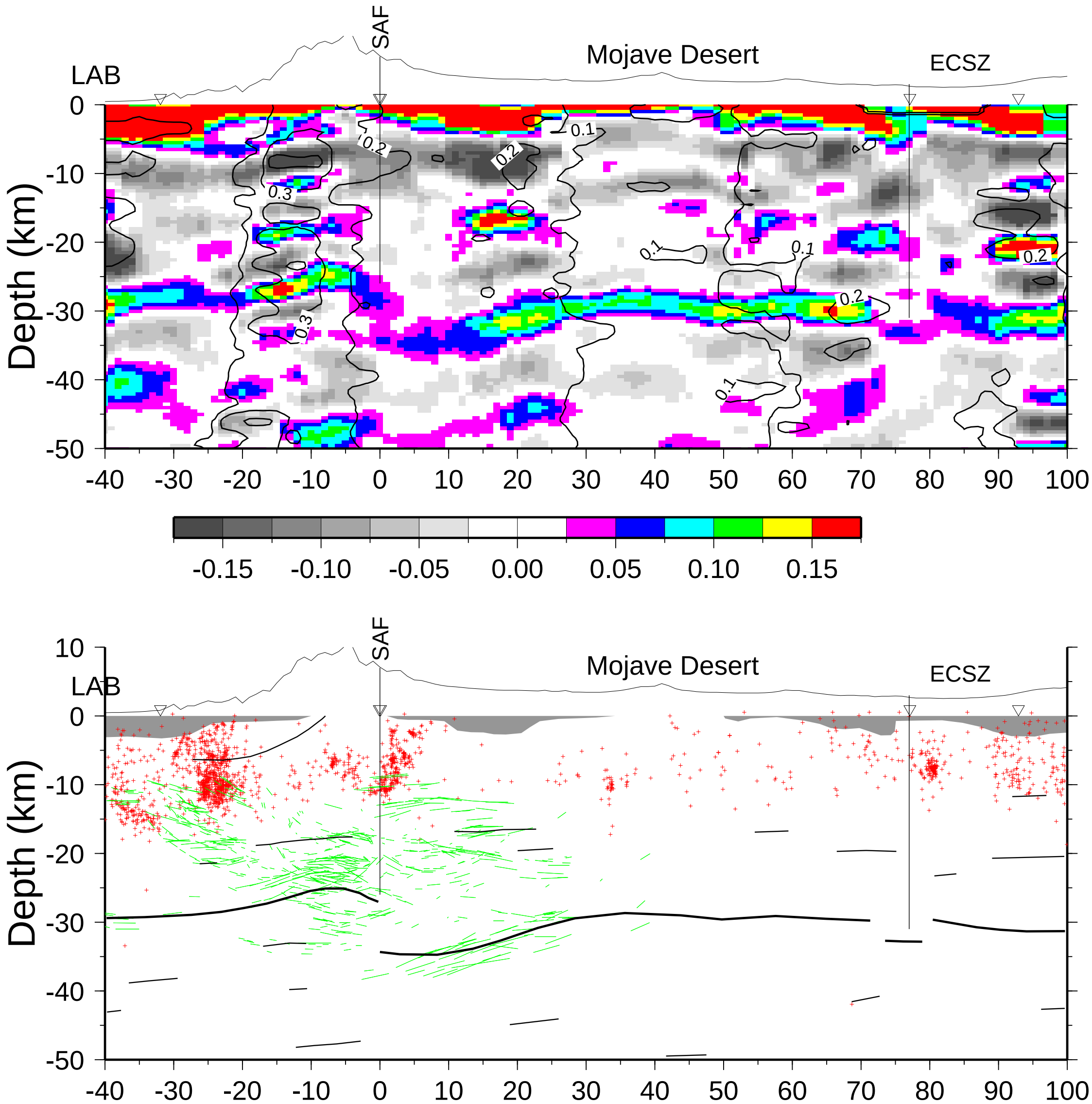

Figure 2: Upper panel: the amplitude and variance (given by the contours) of CCP stacking. Colors represents positive amplitudes of P-to-S conversion. No vertical exaggeration except that the surface topography is amplified by a factor of 4. SAF: San Andreas Fault; LAB: Los Angeles Basin. Lower panel: Crustal structure along the profile based on the image. The thickened black lines are Moho and other possible velocity discontinuities. Green lines are the crustal reflectors imaged by LARSE. Red crosses are earthquakes within the profile between 1981 and 1998.

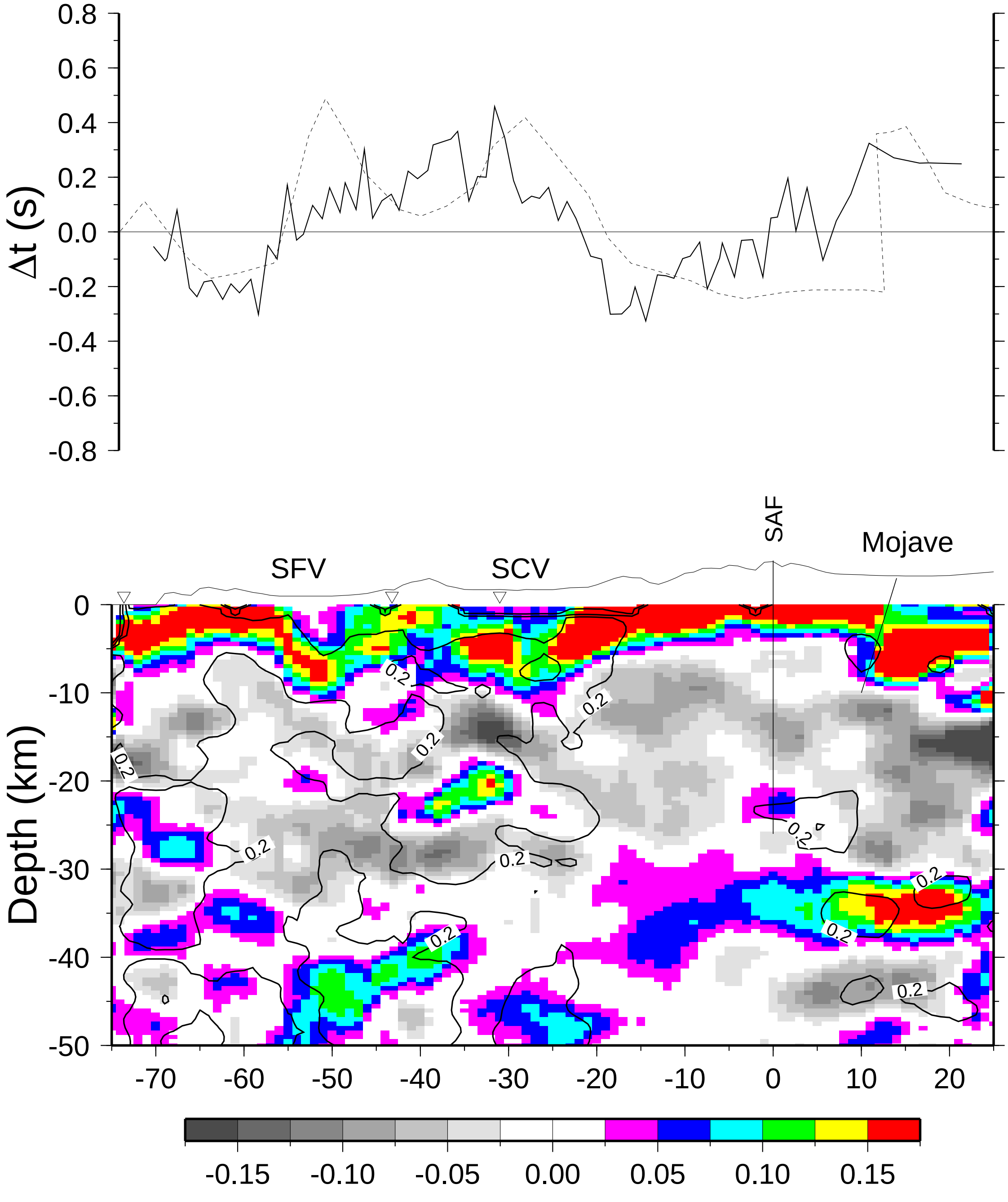

Figure 3: CCP stacking image along the LARSE-II profile, SFV: the San Fernando Valley; SCV: the Santa Clarita Valley. The above is the teleseismic station delays along the profile (solid curve) compared with the thickness variation of near surface sedimentary basins (dashed line) estimated from the CCP image.

(/pub/lupei/jgr2000Moho.grd). For detailed information, contact Lupei Zhu (email: lupei@usc.edu, Tel: 213 740-7088).

References

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[*Kosarev et al.*(1999)*Kosarev, Kind, Sobolev, Yuan, Hanka, and Oreshin*] Kosarev, G., R. Kind, S. Sobolev, X. Yuan, W. Hanka, and S. Oreshin, Seismic evidence for a detached Indian lithospheric mantle beneath Tibet, *SCIENCE*, *283*(5406), 1306–1309, 1999.

[*Zhu and Kanamori*(2000)] Zhu, L., and H. Kanamori, Moho depth variation in southern California from teleseismic receiver functions, *J. Geophys. Res.*, *105*, 2969–2980, 2000.